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vatory, Neue Annalen, Band i., Erstes Münchener Sternverzeichniss von 33082 Sternen, presented by the Observatory; Pulkowa Observatory, Catalog von 5634 Sternen aus den Beobachtungen 1874–80, presented by the Observatory; Photograph of cluster in *Perseus*, made at the Lick Observatory, presented by E. S. Holden.

Further Experience regarding the Magnitude of Stars as obtained by Photography in the Oxford University Observatory. By the Rev. Professor C. Pritchard, D.D., F.R.S.

Notwithstanding all that passed at the recent meeting of the Paris Congress, doubt seems still to exist as to the photographic representation of the photometric magnitudes of the fainter stars, and of the time required for the impression of these faint stars on a photographic film. For instance, the experience of the Oxford Observatory, founded on the examination and discussion of some thirty-six plates, proves that the time necessary for photographing a star of the 11th magnitude, in a condition admitting of bisection and measurement, is on the very finest nights 200 seconds; whereas the experience of Greenwich, founded, it is believed, on the examination of a smaller number of plates, is that, under the same favourable atmospheric conditions, a star of the 11th magnitude may be photographed and subsequently measured after an exposure of only 96 seconds. Under less favourable meteorological conditions, it has been found necessary at Oxford, in order to photograph stars of the 11th magnitude, to prolong the exposure to 5 and even 8 minutes, while at Greenwich an exposure of 4 minutes is the longest contemplated.

I have considered it desirable to examine this question in still greater detail than in the paper which I communicated to the Paris Congress, and I may say that the general result has been to completely confirm the conclusions which I had previously obtained. The methods which I adopted have been twofold. In the first place, I photographed a district, delineated in the charts of the late Professor Peters, with exposures of 3, 4, 6, 8, and 15 minutes. These charts were chosen because they give the configurations of a considerable number of reputed 11th magnitude stars, and therefore permitted an easy comparison. The result of the examination of the plates was as follows:

After 3	min. exposure,	31	per cent. of Peters'	stars were	photographed.
4	,	42	,,	,,	,,
6	,,	62	,,	,,	,,
8	,	78	,,	,,	,,

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But some stars were not visible after 15 minutes' exposure. A photometric determination of the brilliancy of some of the fainter stars with the wedge photometer proved, that

After 4 min. exposure,	stars of	10·5 mag.	were measurable.
6	„	„	11·0 or 11·2	„
8	„	„	11·5 or 11·7	„

This proved that many stars on Professor Peters' charts were fainter than the 11th magnitude, though no symbol indicating a fainter magnitude is used in the construction of the chart.

For this reason, and also because the charts do not extend to an altitude at which the Oxford zone will have to be photographed, it was determined to take an additional trial-plate in the actual zone, and photometrically to measure the magnitude of stars of approximately the 11th magnitude. The night chosen was exceptionally fine and the definition much above the average. An examination of the plate proved that 11th magnitude stars were measurable after 4 minutes' exposure, and possibly after 3 minutes' exposure. It was considered that 3½ minutes or 210 seconds would on that night have been sufficient to effectually record the places of stars of the 11th magnitude.

These discrepancies, if discrepancies they can properly be called, between the results here given and those recorded by the Astronomer Royal may to some extent be explained by the superiority of the Greenwich instrument over that in use at Oxford. The images produced by the Greenwich object-glass are exceptionally small and condensed, and are said to be readily discernible when having a diameter of 2″·5, whereas on the Oxford plates the diameters of the smallest images sufficiently distinct for measurement vary from 3″·2 to 3″·5. The great accuracy of the driving mechanism of the Greenwich Equatoreal, rendering for the most part the uncertain and often exaggerated action of the manual control unnecessary, is doubtless an assistance in producing the small black images characteristic of the Greenwich plates, as exhibited at the Paris Congress. Reference is here made to this fact solely with the view of accounting for the discrepancies which unquestionably exist in the time recorded as necessary for the impression of images of a specified magnitude, such as the 11th. Fortunately, the Congress have recognised the difficulty, and arrived at a practical solution, by recommending each Observatory to determine in its own particular case the time necessary to impress stars of the 11th magnitude on the sensitised film.

The plan proposed by the Congress is that in each Observatory a star of the 11th magnitude shall be artificially formed by reducing a star of the ninth two units of brightness, by means of a metallic gauze of a definite mesh, supplied to each Observatory, and placed in front of the object-glass. Moreover, a small catalogue is to be furnished to each Observatory of stars

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definitely accepted as of the ninth magnitude. As I have myself been placed by the Congress on a committee for the execution of this scheme, I shall, if it be thought desirable by my colleagues, be perfectly ready to furnish the catalogue, and also to examine the gauze necessary for the purpose described. At the same time, I think it will greatly facilitate the object in view, if I were to supplement the necessary list of stars of the 9th magnitude by another catalogue of the 11th magnitude photometrically determined, selected from the same typical areas as those in which the stars of the 9th magnitude will be found. For general convenience this catalogue of stars will be selected from a zone about 8° north of the Equator. The magnitudes of all these stars will be determined at Oxford by the application of the wedge photometer, keeping strictly in view the average scale found in Argelander's work.

The foregoing remarks apply solely to the stars which are intended to form the International Catalogue of all stars to the 11th magnitude, but the Congress have decided that there is to be a chart formed containing stars of a much inferior brightness. It was originally presumed that this order of faintness was to extend to magnitude 14, as defined by the 1887 Congress. Experience, however, has shown that stars of the photometric magnitude 14 require a time of exposure which would render so extensive a chart practically unattainable, and this amount and uncertainty of the time required seems to have led the Congress to the practical issue conveyed by the following minute:—

'Le comité permanent indique quarante minutes comme la durée de la pose pour les clichés de la carte, dans les conditions atmosphériques moyennes à Paris, et avec les plaques Lumière actuellement en usage à Paris.'

As a matter of fact, I believe that no star of magnitude 14 has hitherto been photometrically determined; at all events, I have never been able myself to measure a star of this degree of faintness. The wedges employed for stars, recorded in the *Uranometria Nova Oxoniensis*, when applied to the Oxford 12¼-inch object-glass, extinguish stars between the 9th and 10th magnitude, and are inapplicable to fainter objects. Under these circumstances, I requested Mr. Hilger to furnish me with a wedge capable of determining the magnitude of stars of inferior brightness; and he, not without great difficulty, has constructed for me a wedge applicable to stars a little fainter than magnitude 12. If such a wedge could be applied to an object-glass of twice the aperture of that of the Oxford equatoreal, it would be available for the extinction of stars of the approximate magnitude of 13·5, and if such a wedge were applied to an object-glass three times the aperture—that is, to about the size of the Lick refractor—it might possibly be applicable to the photometric determination of stars about magnitude 14·5. Such,

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then, is the state of the case in reference to existing photometric apparatus, exhibiting the extreme difficulty of the accurate determination of magnitudes so faint. The word "approximately" is here used because it is by no means probable that the light admitted by a thick and compound object-glass is accurately proportioned to the area of glass exposed.

Yet, and notwithstanding these statements, it is quite certain that astronomers, including myself, have repeatedly photographed in the Pleiades stars unquestionably fainter than magnitude 14. In one plate of the Pleiades, taken at Oxford, with a three hours' exposure, I have no manner of doubt but that more than one hundred stars fainter than the 14th are there visibly impressed, and it is equally certain that stars of the 14th magnitude have even been copied therefrom. Still, absolutely accurate measurements of these faint stars are, by me, at least, unattainable. The question, therefore, immediately arises, How can we speak definitely of the order of brightness of these faint Pleiades stars?

In the year 1887, in a paper printed in the Proceedings of the Royal Society, I believe I, for the first time, obtained a mathematical expression connecting photometric brightness with photographic diameter. The formula therein given is the equivalent of the now well-known expression:—

$$M = a - b \log. D.$$

Supposing, then, that proper measurements and this formula are applied to stars on the Pleiades plate already referred to or any other suitable plate, it is possible to determine the constants a and b for that plate, so as to furnish a curve reaching from magnitude 4 to magnitude 12, the stars employed being all photometrically determined. In the actual case quoted, the formula is

$$M = 19{\cdot}23 - 9{\cdot}67 \log. D.$$

That represents all stars to magnitude 12, and theoretically is applicable to stars of a fainter magnitude; but the expediency of thus pushing the formula beyond a magnitude, unascertained by a photometric process, is not established.

To test the applicability of the formula to the determination of the magnitude of stars fainter than those employed in deducing it, I have taken the measured diameters of stars not fainter than the 9th magnitude, and from the expression thus deduced I have computed the diameters of stars of the 11th magnitude which could be directly compared with the measured quantities. I have, also, with a curve founded on measures of stars brighter than the 10th magnitude, deduced the diameters of stars of the twelfth order of brightness. In each case I have found a very close agreement with the diameters read from the curve, the deviation not being greater than is the uncertainty of the interpolating curve itself. From these facts I conclude that

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it is safe to trust the deductions from the equation for at least two magnitudes beyond those employed in deducing it, and that consequently an adequate appreciation of stars of the 14th magnitude is possible.

But when it was originally proposed as a part of the international project to attain a photographic chart of the heavens, including stars of the 14th magnitude, it must not for a moment be overlooked that this magnitude 14 (limited by the definition attached to it by the Congress) did not necessarily mean magnitude 14 photometrically determined.

The definition of photographic magnitude made in 1887 implied that an increase in the intensity of the source of light was exactly equivalent to increasing the time of exposure in the same proportion. I am not disposed to admit or to controvert the general proposition. It certainly wears a general aspect of probability, but if the result of exposure of a plate to stars be measured by the diameters of the discs impressed, which seems to me the only adequate and practical method of measuring the photographic action, I then doubt the proposition altogether. The actinic action must be regarded in its entirety, and surely extends not to the area of the blackened disc alone, but to its depth and its mass. The visibility of the stars on the film, however, depends entirely on the diameter of the disc, though in very feeble stars the colour of the disc is no doubt of importance.

In order to ascertain practically the connection between magnitude and time of exposure, a series of Pleiades plates were taken with exposures of 20^s, 50^s, $2^m\ 5^s$, and so on up to 32^m, each of these exposures being $2\frac{1}{2}$ times that of the preceding, and consequently representing the steps of the conventional consecutive magnitudes. The diameters of the discs of the same star with these various successive exposures were then measured, wherein it is evident, if the diameter be assumed as the measure of actinic action, that the diameter of a star of the 3rd magnitude with the shortest exposure will be the same as that of the 4th magnitude exposed for 2·5 times as long, and the same rule will obtain with feebler magnitudes exposed for a proportionate longer time, it being well understood that the trials extend over a considerable number of stars, but for obvious reasons situated as near the centre of the plate as possible. The invariable result is that the fainter stars require a much longer exposure than that implied by the corresponding powers of 2·5, in order to obtain equality of diameter with the brighter stars. For example, a star of the 5th magnitude with an exposure of 50^s has a diameter of 9 div., but a star of the 9th magnitude exposed for $(2{\cdot}5)^4 \times 50^s$ has a diameter of only 7 div. The following table exhibits the average results of many measurements of the diameters of star-images. The first two columns give respectively the mean photographic and photometric magnitudes of the stars as determined either from the measured diameter of the

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star disc or the wedge photometer. It may be added that the star magnitudes in either column accord very well with those given by other authorities. The remaining columns give the diameters of the measured discs expressed in parts of the scale.

Table showing the mean diameters of groups of stars, given with exposures varying by successive powers of 2·5.

Mean Photographic Magnitude.	Mean Photometric Magnitude.	Diameter, after an exposure of					
		20^{s} div.	50^{s} div.	$2^{\mathrm{m}}\ 5^{\mathrm{s}}$ div.	$5^{\mathrm{m}}\ 12^{\mathrm{s}}$ div.	13^{m} div.	$32^{\mathrm{m}}\ 30^{\mathrm{s}}$ div.
3·46	3·2	9·6	...	...	...	...	...
4·39	4·2	8·2	9·5	...	...	...	...
5·47	5·4	6·25	7·85	9·15	...	...	...
6·51	6·5	4·37	5·90	7·20	8·62	...	...
7·43	7·4	...	3·80	4·90	6·27	7·93	...
8·52	8·4	...	...	3·45	4·45	5·65	7·05
9·46	9·5	...	...	...	3·30	4·4	5 60

The inspection of this representative table is a sufficient indication that the time required for the impression of a star of the 9th magnitude, for example, required to have a definite diameter is by no means sufficiently determined by the continued multiplication of the time required by a brighter star by the appropriate power of 2·5.

It will be seen from this that when the International Committee determined to construct a chart of stars with an exposure of forty minutes, or thereabouts, which time was determined on a certain hypothesis, it must not be expected that the 14th magnitude, as ordinarily or photometrically conceived, will necessarily appear on the plates. As to what order of faintness will be impressed on the average will not be known for a long time to come.

Before concluding this paper it may be as well to state that these numerous measurements of diameter have been completed at Oxford solely by the device of the wedge-lines ruled on a glass plate, described in *Monthly Notices*, vol. li., p. 223. On one plate alone some 800 stars were measured, and the magnitudes determined in about nine hours.